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14. ABSTRACT
Build a compatible set of models which 1) calculate the spectrum of atmospheric GWs excited by a tsunami (using ocean model data as input), 2) propagate these GWs into the thermosphere, and 3) reconstruct the GW field in the thermosphere (e.g., neutral wind, density and temperature perturbations caused by the GWs) as a function of space and time at the altitudes z=200-300 km. These perturbations will then be given to Dr. Makela to calculate the 630 nm airglow and ionospheric response to these GWs.

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Observation and modeling of tsunami-generated gravity waves in the earth's upper atmosphere

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LONG-TERM GOALS

The long-term goal for Dr. Vadas is to determine the response of the thermosphere from z=200-300 km to gravity waves (GWs) excited by realistically-modeled ocean tsunami.

OBJECTIVES

Our objectives are to build a compatible set of models which 1) calculate the spectrum of atmospheric GWs excited by a tsunami (using ocean model data as input), 2) propagate these GWs into the thermosphere, and 3) reconstruct the GW field in the thermosphere (e.g., neutral wind, density and temperature perturbations caused by the GWs) as a function of space and time at the altitudes z=200-300 km. These perturbations will then be given to Dr. Makela to calculate the 630 nm airglow and ionospheric response to these GWs.

APPROACH

Our approach to solving this problem is to derive analytically the Fourier-Laplace compressible solutions to gravity waves (GWs) excited by localized ocean wave packets, program these solutions into a fortran-90 model, input these GWs into our ray trace model, ray trace the GWs into the atmosphere, reconstruct the GW field there, and normalize the spectral GW amplitudes via comparison with the exact solutions. Our approach is then to compute the GWs excited by medium-scale ocean wave packets (with scale sizes typical of tsunamis), ray trace the GWs into the thermosphere through a realistic background atmosphere (which includes variable wind, temperature and viscosity), and reconstruct the GW field. We would then apply our models to several observed tsunamis, and calculate the GW field in the thermosphere for each.

WORK COMPLETED

We completed the analytic derivation of the Fourier-Laplace compressible solutions to GWs excited by an ocean wave packet, including the numerous special cases where the solutions appear to "blow up". Those analytic solutions were then inputted into a fortran-90 code. This year, we modified our ray trace code to input these ocean wave GW solutions via a new and unique "sprinkling" scheme. In this scheme, we randomnly sprinkle several hundred to several thousand GW spectra into the ocean wave

packet region with amplitude weighting factors and unique phases, ray trace the GWs into the atmosphere, and reconstruct the GW field using the GW dissipative polarization relations. Figure 1 (Figure 4 from (Vadas et al, in press) shows the random locations and times generated for one case involving a small-scale ocean wave packet.

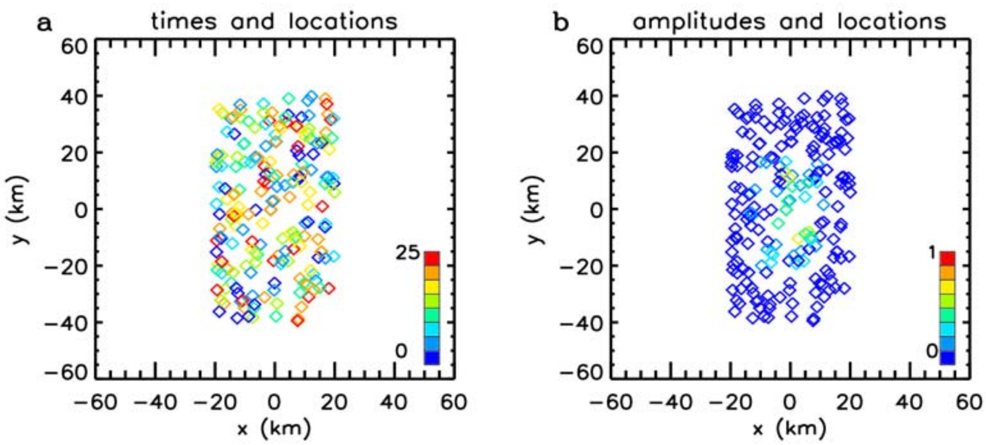

Illustration 1: a) Locations of the 200 GW spectra (diamonds). The times are shown for each spectrum using colors from t=0 (blue) to 25 min (red). b) Same as a), but the colors show the amplitude weight factors from 0 (blue) to 1 (red). (Vadas et al, in press)

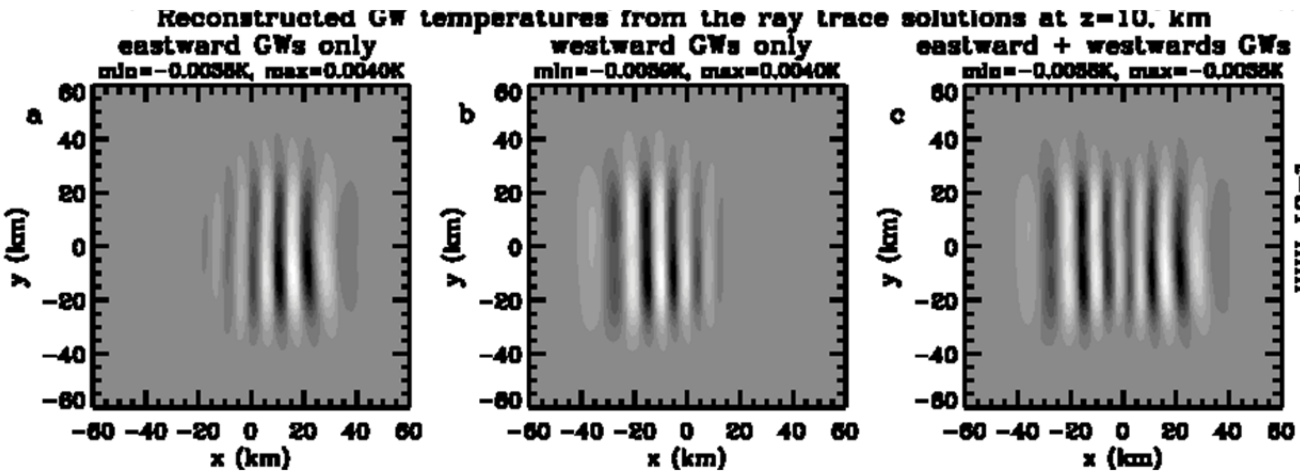

Illustration 2: The temperature perturbation T' for the eastward (a) and westward (b) GWs at z=10 km and t=31 min created by an ocean wave packet with lambda_H=10 km, duration=25 min, fundamental period=10 min, upward ocean wave velocity =0.01 m/s, and sigma_z=1.1 m. c) The sum of a) and b). Minimum and maximum values are shown in the title of each image. (Vadas et al, in press)

We calculated the GWs excited by a small-scale ocean wave packet, ray traced the GWs into the upper troposphere through a windless, isothermal, non-dissipative atmosphere, and reconstructed the GW field there. Figure 2 (Figure 5a-c from Vadas et al, in press) shows the reconstructed GW field in the upper troposphere from a small-scale ocean wave packet. Here, we ray trace the eastward (left panel) and westward (middle panel) GWs separately in order to accurately determine the average horizontal wavevectors for each “cell” in the troposphere. These average values are then used along with the GW momentum fluxes and GW polarization relations to reconstruct the GW field. The final solution is the eastward plus westward solutions (right hand panel).

We then compared these solutions with the exact Fourier-Laplace solutions. We found that the ray trace solutions agreed reasonably well with the exact solutions. We used this comparison to determine the normaliation factor needed in the ray trace code to convert the GW spectral amplitudes into real-space amplitudes. (This is essential for reconstructing the GW fields.)

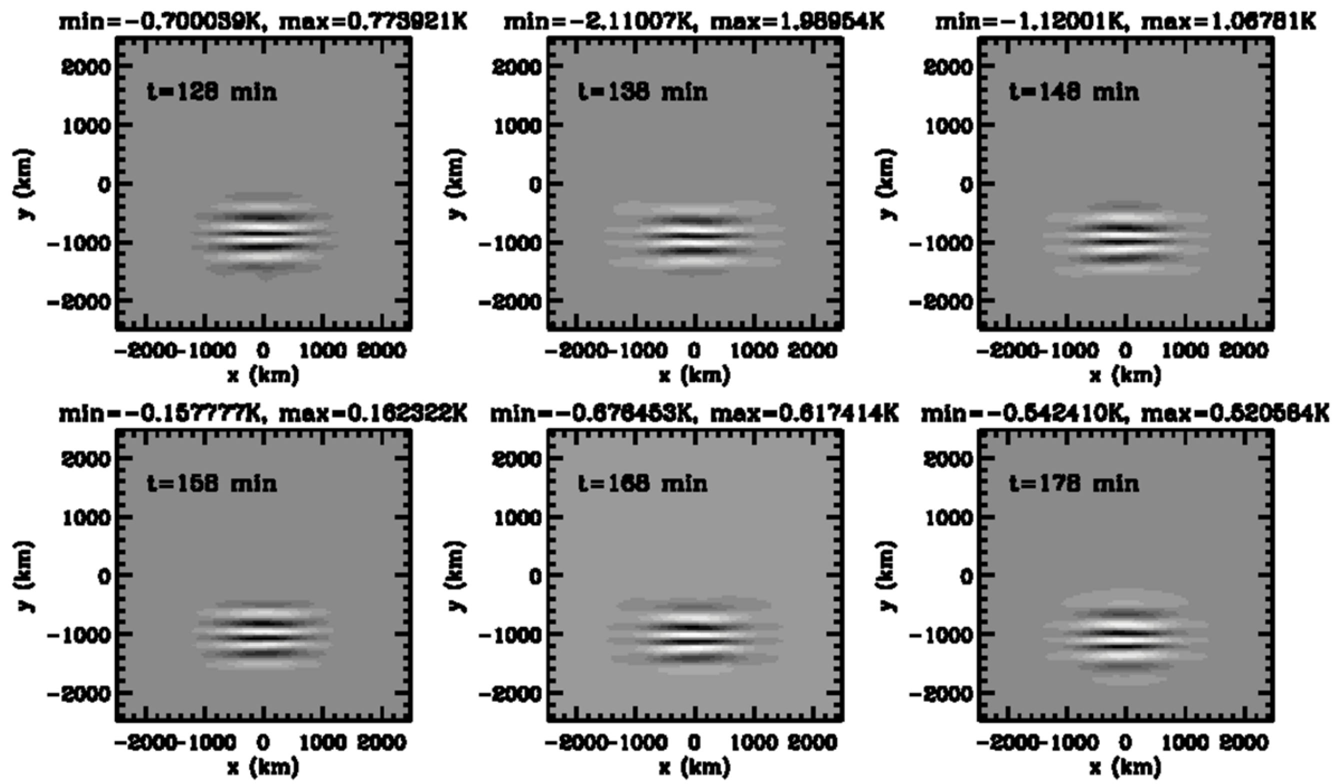

Illustration 3: Reconstructed T' at z=250 km for the southward-propagating GWs every 10 minutes from t=128 to 178 min, as labeled. The ocean wave packet has fundamental period=14 min, lambda_H=190 km and duration=30 min. (Vadas et al, in press)

We then calculated the GW spectrum excited by a southward-moving medium scale ocean wave packet with horizontal wavelength lambda_H=190 km and fundamental period=14 min. These scales are similar to the leading edge of the Tohoku tsunami, which contains the largest amplitude and largest horizontal wavelength GWs that are therefore most important for the thermosphere. We randomnly sprinkled the GW spectra throughout the excitation region, ray traced the GWs into the thermosphere,

and reconstructed the GW field there. Figure 3 (Figure 9 from Vadas et al, in press) shows the reconstructed solutions at z=250 km. We see GWs with lambda_H=190 km moving southward in time.

We wrote up these results (i.e., the new compressible Fourier-Laplace solutions, the new ray trace sprinkling scheme, and the thermospheric results) into a paper which we submitted to JGR Space Physics last spring. The editor recently informed us that this paper has been accepted for publication in JGR. The reference for this paper is:

Vadas, S.L., J. Makela, M.J. Nicolls and R.F. Milliff, "Excitation of gravity waves from ocean surface packets, propagation into the thermosphere, and reconstruction of the gravity wave field", JGR Space Physics, in press.

RESULTS

We analyzed the GW spectra excited by medium-scale ocean wave packets in detail in Vadas et al (JGR, in press). We found that the excited GWs have the fundamental frequency (which is the same as that of the ocean wave), the fundamental frequency +- 2 pi/wave packet duration, and a continuum of frequencies. We found that the initial momentum flux amplitude is largest for those GWs having the fundamental frequency. But those GWs with frequencies larger than the fundamental frequency suffer less dissipation in the thermosphere (as compared to those GWs having the fundamental frequency), if they survive without reflecting downward (because the buoyancy period increases in the thermosphere).   Therefore, it is no surprise that we found that the resulting temperature perturbations T' at z=250 km for those GWs with frequencies larger than the fundamental frequency are larger than those GWs having the fundamental frequency for these cases. This is shown in Figure 4 (Figure 16a-b from Vadas et al, in press). Here, the fundamental period is =20 min.

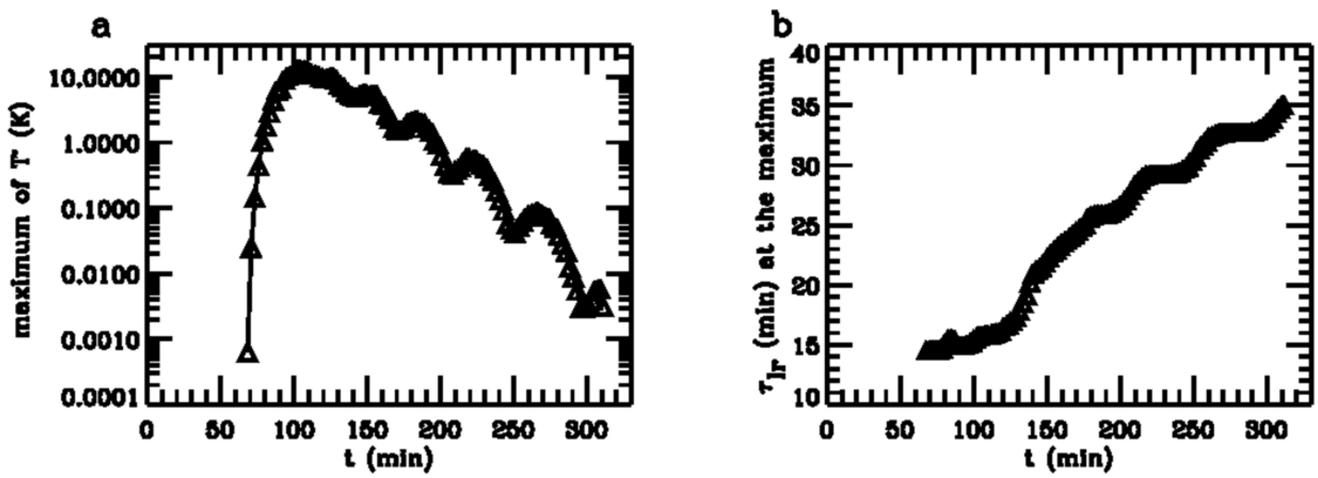

Illustration 4: a) Maximum T' at z=250 km for the GWs excited by an ocean wave packet with fundamental period=20 min, lambda_H=190 km, and duration=50 min. b) The average GW period. *(Vadas et al, in press)*

We also found that these higher-frequency GWs shown in Figure 4 had much larger horizontal phase speeds, and therefore arrived at a specific latitude/longitude prior to the tsunami. We postulated that these super-fast GWs could have been responsible for the observation that GWs arrived in the 630 nm

airglow layer over Hawaii approximately 1 hour before the tsunami reached Hawaii (Makela et al, 2011) . (Other theoretical models could not explain this behavior, as described in Makela et al, 2011.) This behavior is shown in Figure 5 (Figure 17 from Vadas et al, in press). Here, the dotted line shows the location of the southward-moving tsunami. Indeed, southward-moving GWs are seen well south of the dotted line (tsunami location).

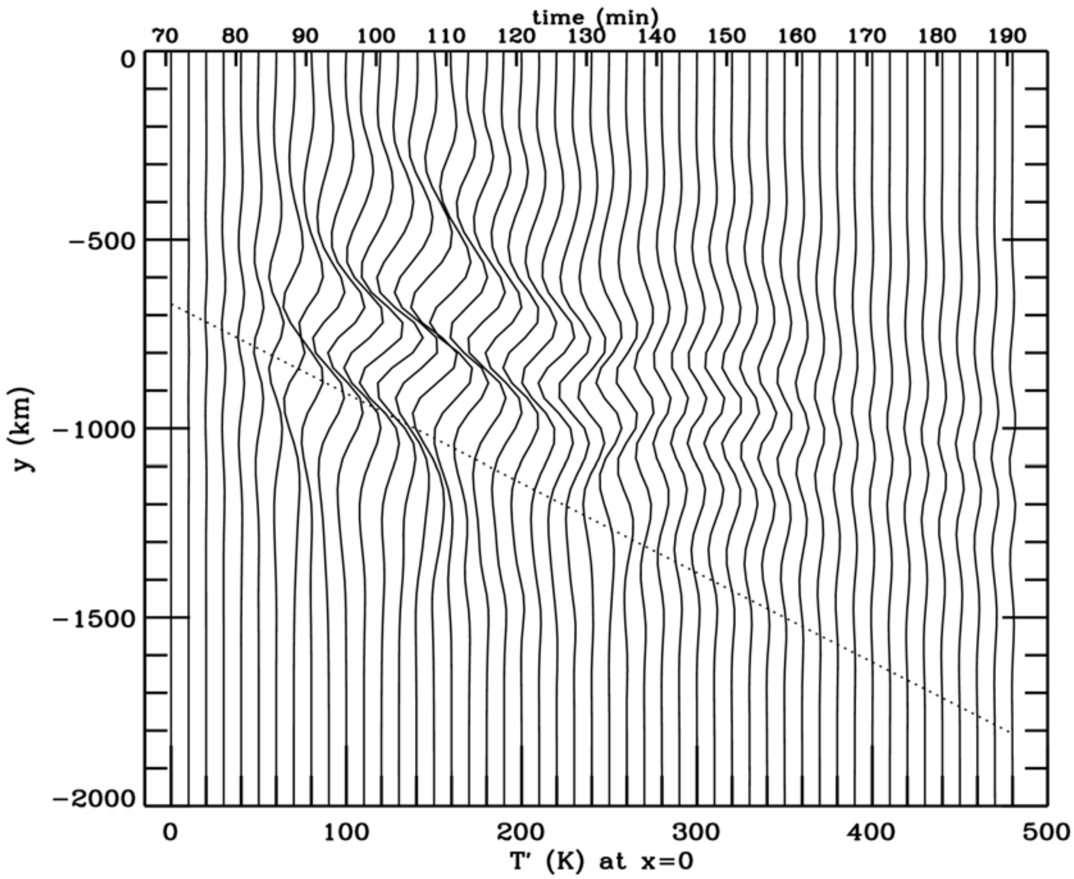

Illustration 5: T' at x=0 and z=250 km for the GWs excited by an ocean wave packet with fundamental period=20 min, lambda_H=190 km, and duration=50 min every 2.5 min from t=70.75 to 190.75 min. Profiles are offset by 10 K. The upper x-axis shows the time t. The dotted line shows the location of the ocean wave packet. (Vadas et al, in press)

WORK IN PROGRESS

We will complete the page proofs for the Vadas et al paper. We are waiting for the completion of the ocean wave solutions by researchers in France for a recent tsunami. Using these ocean wave solutions, we will determine how to implement our scheme for a moving tsunami (since the scheme used above was for a “snapshot” of a tsunami). We will then determine the GW field in the thermosphere from the tsunami. Additionally, there is a free parameter in the tsunami model discussed above (i.e., sigma_z, which is the Gaussian height above the ocean surface for which the air is directly accelerated by the tsunami). The amplitude of the GW response is roughly proportional to sigma_z. We will

compare the modeled ionospheric response for a tsunami with data to determine sigma_z. We will then apply this model to another tsunami to see if the calculated response is consistent with the data.

We are scheduled to present an oral talk, “The affect on the thermosphere and ionosphere of atmospheric gravity waves excited by tsunamis”, on Wednesday, 16 December 2015 at the fall AGU meeting in the session entitled “NH32C: Seismology without Seismometers: Ionospheric Monitoring of Natural Hazards of Earth, Ocean, and Atmosphere II”. We will present the results from the Vadas et al paper (in press) as well as any new tsunami modeling results.

IMPACT/APPLICATIONS

Because our GW excitation/propagation/reconstruction model includes compressibility and thermospheric dissipation in a generalized wave packet formulation, it may provide a better and more complete understanding for the effect of tsunamis on the 630 nm airglow emission and the ionosphere. This would greatly enhance our ability to detect tsunamis in the ionosphere.

RELATED PROJECTS

Not at this time.